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THE ECONOMIC DAMAGES OF AIR POLLUTION

by

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ABSTRACT

Air pollution is a problem because it endangers man's health and the environment in which he lives. The information researched in this report indicates that the cost of air pollution damage in 1970 (for measured effects only) falls within a range of $6.1 to $18.5 billion, with a "best" estimate of $12.3 billion. These estimates are based on: (1) a survey of the literature on environmental economics; (2) a critical review of completed studies that have attempted to estimate air pollution damages; and (3) prevailing air quality levels in 1970. Such information on air pollution damages provides policy-makers with some understanding of the seriousness of the air pollution problem, and with some knowledge of the potential benefits -of abating air pollutant emissions.

A benefit-cost analytical framework for environmental decision-makinq is outlined. The methods that have been or can be used to estimate the damaqes of air pollution are identified. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys: (5) political expressions of social choice; and (6) the delphi method. The strengths and weaknesses of each method are discussed.

The technical coefficients method is utilized in estimating the value of air pollution damage to human health, to man-made materials, and to vegetation. The "best" estimates of damages for these effect categories for 1970 are $4.6 billion for health, $1.7 billion (adjusted for double-counting) for materials, and $.2 billion for vegetation. A particular market study method, the site differential or property value approach, yielded a "best" damaqe estimate of$5.8 billion (adjusted for double-counting) for aesthetic and soiling-related costs. Economic losses associated with air pollution effects on domestic animals and wildlife and the natural environment are not estimated because of data limitations.

Estimates of damages are allocated by major pollutant and source categories. The utility and limitations of gross damage estimates are discussed, and comparison with other such estimates is made. One of the major information gaps identified is the economic effects of automobile and related air pollutants on human health and welfare,

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SECTION I

SUMMARY AND CONCLUSIONS

The cost of air pollution damage in the United States in 1970 is estimated to fall within the range of $6.1 billion and $18.5 billion. The "best" estimate for measured effects for that year is determined to be $12.3 billion. These estimates are based on: (1) a survey of the literature on environmental economics; (2) an extrapolation of studies that have attempted to estimate air pollution damages and that passed a critical review; and (3) prevailing air quality levels in 1970.

An evaluation is also made of the methods that can be employed to estimate the damages of air pollution. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the delphi method. It is concluded from such a review that some combination of the methods surveyed will ensure the most accurate assessment of the economic damages resulting from air pollution insults. Such damages, in turn, when properly translated, become the benefits of abating air pollutant emissions.

It is shown in this report that only the technical coefficients and market study approaches have been used with measurable success in assessing the benefits of controlling air pollution. The technical coefficients method was utilized in estimating air pollution damages to human health, man-made materials, and vegetation. The "best" (unadjusted) estimates for these effect categories for 1970 are $4.6 billion for health, $2.2 billion for materials, and $.2 billion for vegetation, and total to $7.0 billion. A market study method, the site value differential or property value approach, yielded a "best" (unadjusted) estimate of $5.9 billion. This figure represents the value in 1970 of the negative insults of air pollution that are capitalized in the residential, urban property market. It is argued in this report that capitalized in this estimate are primarily those costs associated with aesthetics and household soiling.

Since it is likely that there is some overlap in the $7.0 billion and $5.9 billion estimates, they can be considered additive only with minor adjustments. By making such adjustments, any double-counting will be minimized. With such adjustments, the $7.0 billion determined via the technical coefficients method becomes $6.5 billion and the $5.9 billion determined via the property value method becomes $5.8 billion.

The estimate of $12.3 billion for 1970 developed here, differs from the 1968 estimate of $16.1 billion developed by Barrett and Waddell because of the following reasons: (1) the 1970 estimate is based on information that wasn't available in the 1968 study; (2) the levels of air pollutants being worked with in the 1970 study are generally lower than the levels for those same pollutants in 1968; (3) a re-evaluation of the available data has forced the modification of certain assumptions in this report.

The information surveyed in this report establishes that $12.3 billion is the "best" estimate for 1970. Given the lack of conclusive information to indicate that what Is estimated in the $5.9 billion does not significantly overlap with what is estimated by the $7.0 figure, the option is left for the reader to use the $7.0 billion as a measure of air pollution damages in 1970. While the evidence is far from clear, it is reasoned that as interpreted in this study, the estimates determined via the site differential and technical coefficients methods should be considered additive, with only minor adjustment for obvious areas of overlap.

While it is known that air pollution causes losses of domestic animals and wildlife, such losses were not quantified in this report because of data limitations. Air pollution is also believed to cause pervasive effects in the biosphere and on geophysical and social processes. These effects are not without some economic consequences, but until the relationships can be more clearly identifled, large-system economic analysis is somewhat premature.

The cost estimates for aesthetics and soiling, health, materials, and vegetation are distributed among the several pollutants considered responsible for the effect. The pollutants considered are sulfur oxides (SO,), particulates, and oxidants (0,). Damages in 1970 attributable to SO, are estimated to fall within the range \$2.8 - \$8.0 billion, with a "best" estimate of \$5.4 billion. Particulate damages are estimated to fall between \$2.7 and \$8.9 billion, with a "best" estimate of \$5.8 billion. Oxidant-related damages are estimated to fall in the range \$0.6 - \$1.6 billion, with a "best" estimate of \$1.1 billion. Every attempt is made in this attribution process to identify where data deficiencies precluded the generation of estimates. For example, health costs associated with oxidant-related air pollutants are not estimated because of the lack of data.

The same costs are distributed among sources on the basis of the relative level of pollutant emissions. Damages of \$6.1 billion in 1970 are attributed to the general source category, fuel combustion in stationary sources. Damages of \$4.0 billion are attributed to industrial process losses, \$1.1 billion to transportation, \$0.4 billion to both the agricultural burning and the miscellaneous categories and \$0.3 billion to solid waste disposal.

Although estimates are obtained and presented, the reader is cautioned concerning their use. The estimate of air pollution damages of \$12.3 billion Is not to be taken as absolute, but is to be considered as indicative of the seriousness of the air pollution problem. The range of \$6.1 to \$18.5 represents the significant uncertainty in which the 'best" estimate of \$12.3 billion should be couched. Limitations of gross damage estimates are spelled out in greater detail in'the paper. There is certainly at least one significant limitation: many benefits to be gained from air pollution control are not yet amenable to quantification in dollars and cents. Thus, the decision framework set up in the paper is designed to take this limitation into consideration.

While these estimates provide some basic justification for environmental policies and programs, aggregate point estimate offer little policy information for setting environmental standards. The research identified in this report needs to be extended to determine more accurate dose-response relationships, i.e. damage functions, and the economicvalue of the receptor response over a range of pollution levels. Such information would be very useful for decision-making in matters relating to environmental management.

SECTION II
INTRODUCTION

CLEAN AIR: A SCARCE NATURAL RESOURCE

Only recently has clean air been perceived as a resource which is limited, and sometimes scarce, so that society must become involved in deciding how it is to be used. This is the fundamental argument: air pollution damages human health and welfare. But it is also true that the abatement of pollution will necessitate the use of natural, human, and capital resource--all of which may be scarce.

In other terms, air pollution results in (external) costs that must be borne by the community (i.e., increased medical and cleaning expenditures, etc.); and in the same sense, the abatement of air pollution necessitates the use of resources that could be used for other competing social goals (improved education, urban renewal, etc.). These are the two significant aspects of the environmental pollution problem. And it seems that it is here that the question of "How clean is clean enough?" is relevant. In a world where knowledge of the costs and benefits of air pollution control, implementation costs, and income redistribution or burden considerations are not known with precision, it is a very difficult task to determine environmental policy.

WHY SHOULD GOVERNMENT ACT?

The concept of "externalities" is becoming well recognized and understood. Externalities of pollution are the adverse (negative externalities) or favorable (positive externalities) effects of residuals produced by consumption, production, and distribution activities. Typically, full payment for positive externalities or full compensation for negative externalities to the party affected is not made. These compensations are not required under existing economic and legal mechanisms. Society is interested because it believes that under alternative economic and legal arrangements, positive externalities could be increased and negative externalities could be decreased until, ideally, net gains are maximized.

Air pollution represents a classic example of a negative externality. The atmosphere is a common property resource providing two services: (1) removal of waste residuals discharged by firms and individuals, and "life support" for individuals, including "support" of aesthetics and concern of individuals for future generations; and (2) "support" of material objects that individuals own. As long as there is no conflict between the two services, then there is in effect no pollution. But when the two are incompatible, negative externalities can exist.

There are many actions which are not externalities even though they possess some of the characteristics of an externality. For example, goods production and trade--positive actions--have been internalized by the market system. Traffic congestion--a negative action--has been internalized to some extent, by traffic lights and the willingness of individuals to obey them. Assigning "responsibility" or "ownership" and devising enforcement mechanisms for the purpose of achieving net gains are means of internalizing externalities. Unfortunately, comparable, "naturally evolved" institutional frameworks for internalizing air pollution costs, frequently do not exist. Such institutions do not exist because: (1) ownership of air cannot be easily defined; (2) air "congestion", for large segments of the population, has risen to the "peril" point (in a physical sense) only in recent times; and (3) only in recent times have individuals perceived air pollution as "perilous" (in both a physical and a metaphysical sence) relative to their other wants.

At first glance, one might think that traditional adaptive institutions, like the market and common law legal systems, would eventually provide a means of, internalizing air pollution. But this is not likely to happen. Because the atmosphere is a Crocker property resource and because ownership rights cannot be exclusively defined, air rights cannot, in a traditional sense, be bought and sold-in a market. Moreover, costs of common law legal settlements are often prohibitive. Many individuals are affected 'by air pollution. This pollution often comes from a number of sources. It is extremely difficult and costly to reach agreement, within a group of affected individuals, on the extent and nature of their air pollution damages and then show in a court of law, the source of these damages.

On these bases, government regulation of air pollution is necessary and desirable. It is desirable that these regulations be designed to replicate the workings of traditional market institutions. In other words, an efficient allocation of resources will be attained when polluters act as if the costs their activities impose upon others are their own costs. A government acting to ensure efficiency should establish mechanisms such that net gains from pollution control are maximized. This government action will, ideally and as a first approximation, require standards set at a level where marginal costs of control including implementation costs equal marginal control benefits. To achieve such standards, government might provide regional planning and assign emission reductions (perhaps, for example, through the use of effluent charges) so as to minimize the costs of achieving established air quality standards in an affected region, and/or establish mechanisms for minimizing implementation costs. These are costs, for example, of setting, administering, and enforcing environmental standards.

In effect, a government operating in this fashion--setting and enforcing environmental standards so as to maximize net gains--would be internalizing air pollution externalities. Through this internalization government would be ensuring an economically efficient allocation of scarce air resources.

A FRAMEWORK FOR ANALYSIS

In a wider decision framework, however, income redistribution or burden considerations must be coupled with efficiency considerations. Who pays the cost of pollution control? Who benefits? Is the resulting income redistribution a socially "fair" one? These latter equity considerations might very well temper allocative considerations and result in smaller net efficiency gains. Political processes, in trading off efficiency gains against income redistribution or burden considerations would, in the main, determine the outcome. Nonetheless, whatever the result, it is possible in principle (as shown later) to determine the costs of various income redistribution or burden outcomes in terms of foregone efficiency gains.'

To sum up, the decision-maker setting environmental standards should be fully aware of all of the consequence of his actions. For various alternative enforcement schemes and for the region under study, he should be provided with comprehensive estimates of pollution control costs including direct, indirect, and implementation costs, and with comprehensive estimates of benefits and "burden" impacts. Some benefits can reasonably be measured in dollars with confidence bands; other classes of benefits can only be described in physical terms. But both costs and benefits (however quantiffed) and "burden" impacts should be estimated over a range of pollution control levels.

What Information is Needed?

Four lists of information--what economists call functions--are needed for presentation to environmental managers. The first list or function would display all of the appropriate costs of pollution control which would be incurred in meeting a range of pollution control levels. This list would include: (1) the direct costs of installing and operating pollution control equipment, or the extra, direct costs of undertaking process changes which result in less pollution; (2) indirect costs such as the differential costs of retraining and relocating workers when plants are retired earlier than otherwise because of the enforcement of environmental policies; and (3) costs of setting, administering, and enforcing environmental policies--so-called implementation costs.

Actually, there would be a series of these cost functions, each corresponding to a specific way of allocating emission reductions among the affected emission sources,:, For example, reductions could be allocated proportionately with each 'emission source being required to reduce its emissions by the same percentage; or, alternatively, reductions could be allocated so that for each overall level of control, specific sources incur the same cost of control on the last unit of pollution controlled. Strictly in terms of direct, indirect, and implementation costs, proportionate reduction--i.e., a 90% reduction in emissions by all polluters--is likely to be more expensive than marginally allocated reduction which treats emitters individually. The proportionate reduction approach may be chosen, however, if political considerations outweigh the extra control costs which are incurred.

In order to further clarify these concepts of tradeoffs, two cost curves or functions, Cl and C2, are illustrated in Figure 1. Control costs--including direct, indirect, and implementation costs--are measured in dollars-per-year ($/year) along the ordinate; degree of pollution control (tons/year) is measured along the abscissa. As the control level increases, empirical studies' have shown that the costs of control are likely to rise at an increasing rate, thus the upward bow of curves Cl and C2. Curve Cl is an example of a cost function associated with a relatively expensive way of allocating emission reductions (say, proportionate reduction) while C2 exemplifies a cost function associated with a less costly way of allocating emission reductions (say, marginally allocated reduction).

KEY: C1 = Expensive Control Instrument
C2 = Inexpensive Control Instrument
DBU = Dollar Benefits (Upper Limits)
DB = Dollar Benefits
DBL = Dollar Benefits (Lower Limits)

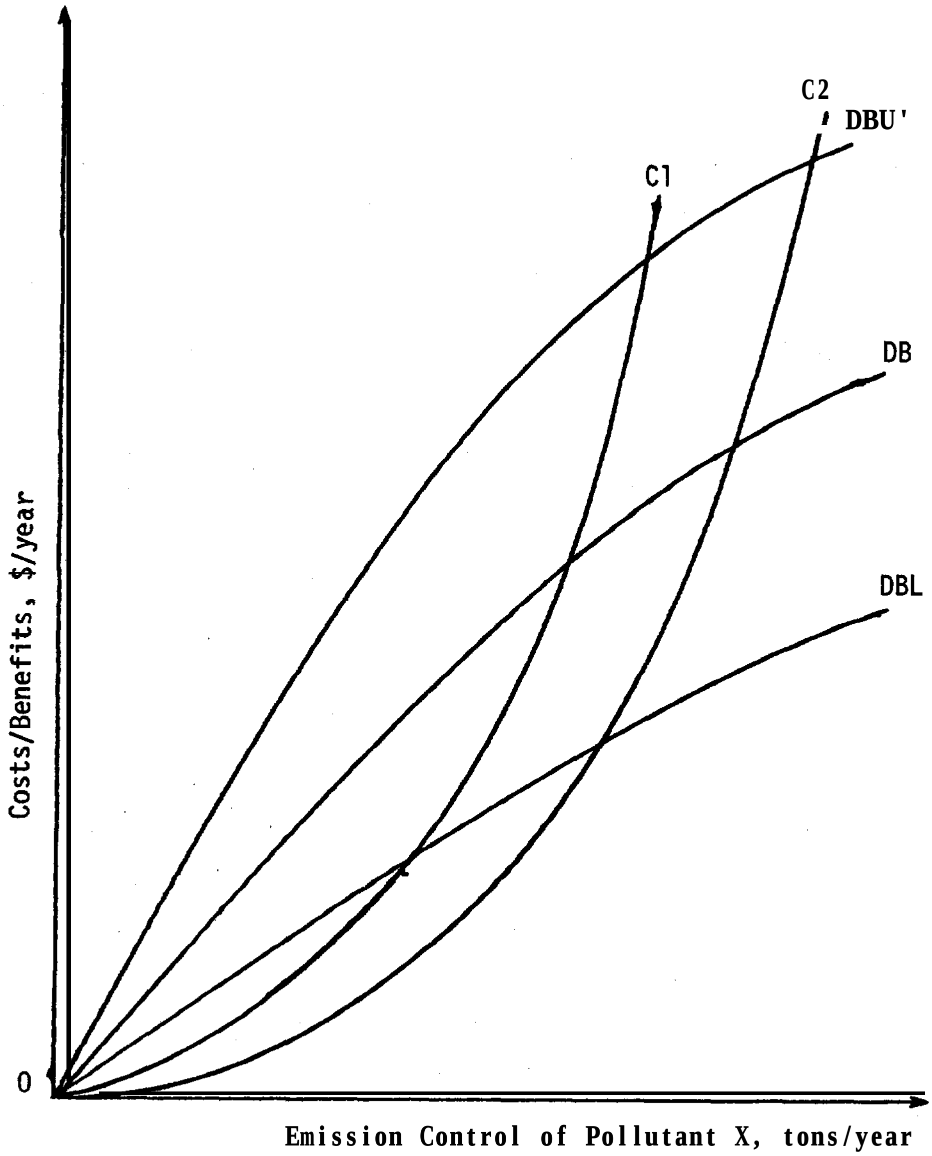

Figure 1. Total Air Pollution Costs and Benefits for Hypothetical Region Z

The second list of information or function needed for policy-making, would display, over a range of pollution control levels, those benefits resulting from pollution control which can reasonably be measured in dollars--a benefit function. Such benefits might include, for example, avoided out-of-pocket costs of soiling incurred by individuals living in a polluted environment. But these out-of-pocket costs would not cover all of the "true" costs in the soiling category. For example, individuals probably adjust to a dirty environment, in part, by undertaking extra cleaning and, in part, by relaxing their cleanliness standards, A dollar quantification of extra out-of-pocket soiling costs would probably not consider many of these "adjustment" costs. At present, there is no well-defined method of measuring in dollars, "psychic costs" resulting from a relaxation of cleanliness starldards. To take another example, health benefits of pollution control could be partially quantified by measuring the health care costs which individuals would incur in a dirty environment. However, out-of-pocket costs for health care are not necessarily adequate measures of willingness to pay for such care. Therefore, given the current state-of-art, it is extremely difficult to quantify dollar benefits in some categories. Methods that have been used to quantify damages--which become benefits with effective abatement--will be reviewed in Section III.

It is useful, however, to measure those dollar benefits that can be quantified in a way which reflects the uncertainty of our benefit measures. For example, empirical studies indicate that it is extremely difficult to isolate the extra out-of-pocket health care costs associated with living in a polluted environment. Pollution is only one of a number of factors which influence health care expenditures. One solution is to use confidence bands to reflect uncertainty in benefit measures by indicating upper and lower benefit numbers within which there is, say, a 90% chance that the true benefit number lies. These confidence bands can be based upon statistical procedures, if, for example, benefit functions are quantified using statistical procedures such as regression analysis. Even in those cases where benefit measures are judgmental, benefit analysts should be asked to provide upper and lower bounds' on their benefit estimates.

A dollar benefit curve or function, DB, has been drawn in Figure 1 to clarify these concepts. Curve DB represents the measured benefits in dollars over a range of control levels. It includes only benefits which can reasonbly be measured in dollars such as avoided out-of-pocket cleaning costs and avoided out-of-pocket health care costs. The function DB could be derived by estimating avoided dollar costs (i.e., dollar benefits) in a cleaner air environment where the air environment is characterized by ambient air quality and then relating these benefits to actual reductions in emissions from specific sources using an atmospheric dispersion model. In practice it may be very difficult to make this latter transformation. The curves DBL and DBU are lower and upper confidence limits on dollar benefits, respectively. They are meant to display uncertain knowledge of dollar benefits and are drawn to cover some specified range of confidence, say, for example, 90%. This range is to reflect uncertainty in dollar quantification of benefits relative to ambient air quality and uncertainty in transforming ambient air quality into specific emission reductions.

Most of our dollar benefit measurements, such as the ones reviewed in this report, have been taken in relatively dirty environments employing devices and methodologies which are tuned to these more severe conditions. Relatively less is known about dollar benefits in a cleaner environment. Hence the upper and lower hypothetical confidence limits on measured dollar benefits, DBU and DBL, have been drawn in Figure 1 with a widening spread to reflect this increased uncertainty. The bowed-over shapes of the dollar benefit functions reflect the assumption that benefits from increasing levels of pollution control, increase at a decreasing rate.

The third list of information needed for the setting of standards is a tabulation of all of the benefits from pollution control which cannot reasonably be measured in dollars. The previously mentioned psychic benefits from improved health and higher cleanliness standards, are examples. These non-dollar benefits should be fully described in physical terms over a range of control levels. Information should be provided on the numbers and characteristics of the human, plant, and animal populations and inanimate objects which are impacted by these non-dollar benefits.

The fourth list of information needed for policy-making is a description of income redistribution or burden impacts. Who are the gainers and who are the losers? Who are affected, and to what degree, by residual pollutants after standards are implemented? This information should be provided over a range of pollution control levels.

All of this cost, benefit and "burden" information should be related to specific pollutants (or groups of pollutants when effects are synergistic) and to specific regions. Weather conditions, topography, climate, the mix of emission sources, and sensitivity of the exposed population vary over time and from location to location. Furthermore, income redistribution or burden considerations may be important for particular regions and for specific sources of particular pollutants and may point to politically attractive enforcement schemes for these regions and these pollutants. In view of these temporal and spatial considerations, cost-benefit analysis can be done for different time periods on a regional basis, either for individual pollutants or mixes of pollutants. For example, in dealing with mixes of pollutants, cost savings on control systems and reduction of damage function problems are possible by solving problems of individual (but related) pollutants with a package approach.

A Hypothetical Example - Decision-Making

A hypothetical example should aid in putting into better perspective the previous discussion on what information is needed by the decision-maker. Let's now assume: (1) that a decision-maker is interested in controlling pollutant X in region Z; (2) that relevant estimates of total dollar costs, and total benefits (dollar and non-dollar), and "burden" impacts for all politically acceptable alternative enforcement schemes (say, there are only two: proportionate reduction and marginally allocated reduction) are available[3]; and (3) that this information (except for non-dollar benefits and "burden" impacts) is summarized in the cost and benefit curves drawn in Figure 1. The decision-maker has responsibility for establishing an ambient air quality level for pollutant X and would like to know the cost-benefit implications of a range of levels.

KEY:
MC1 = Marginal Control Cost (Expensive)
MC2 = Marginal Control Cost (Inexpensive)
MBU' = Marginal Benefit-Upper (Includes' Dollar and Non-Dollar Benefits)
MBU = Marginal Benefit-Upper (Includes Only Dollar Benefits)
MB = Marginal Benefit Function
MBL' = Marginal Benefit-Lower (Includes Dollar and Non-Dollar Benefits)
MBL = Marginal Benefit-Lower (Includes Only Dollar Benefits)

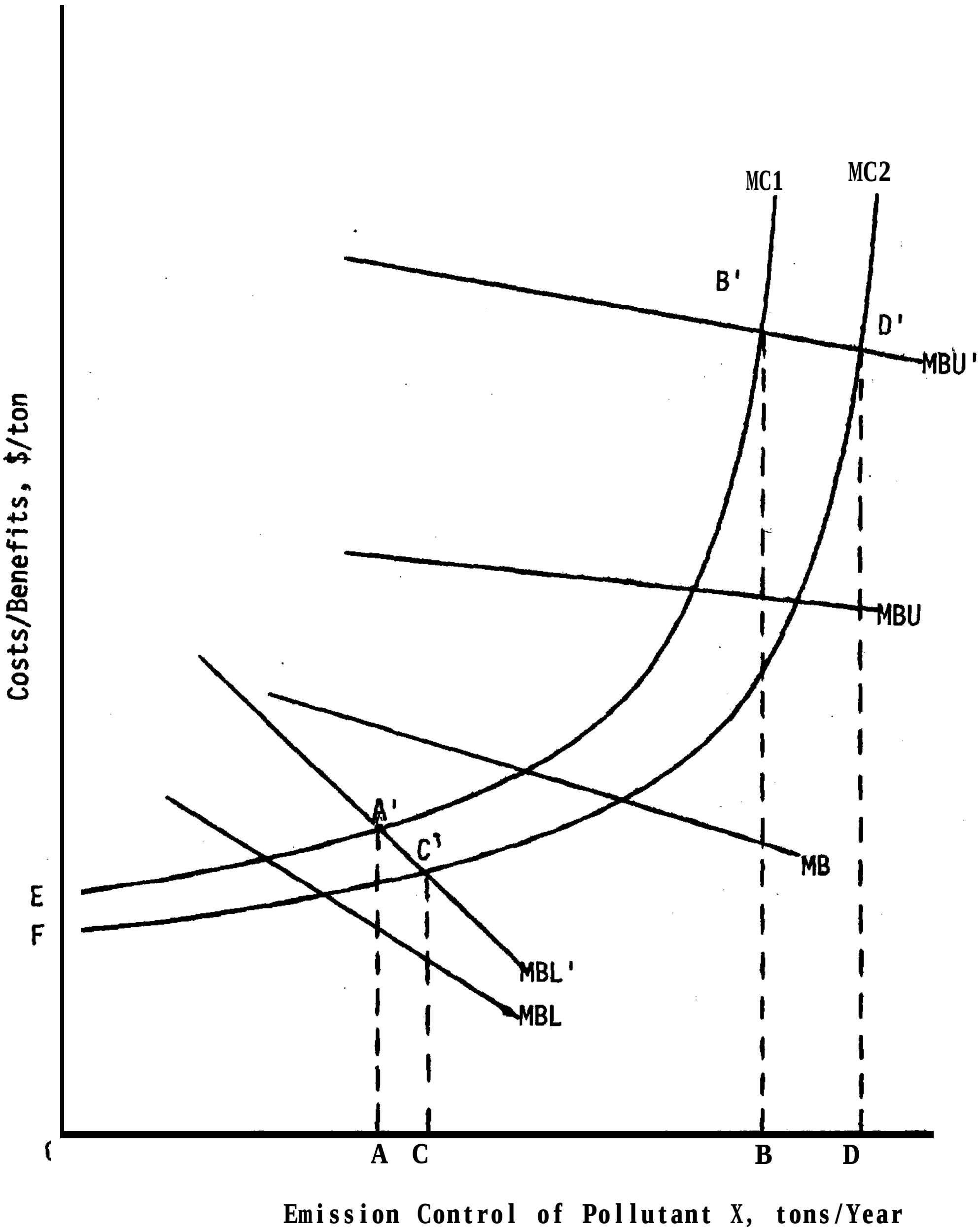

Figure 2. Marginal Air Pollution Costs and Benefits for Hypothetical Region Z

A useful way in which to present dollar cost-benefit information to the decision-maker is in the form of marginal cost and benefit curves. These are drawn in Figure 2. The units on the vertical axis are dollars per ton ($/ton); units on the horizontal axis are tons removed per year (tons/year). Curves MB, MBU, and MBL are marginal benefit, and upper and lower (confidence) marginal benefit curves--the first derivatives of curves DB, DBU, and DBL in Figure 1--respectively. MC1 is the marginal cost curve for proportionate reduction and MC2 is the marginal cost curve for marginally allocated reduction--the first derivatives of the Cl and C2 curves in Figure 1--respectively.

Implicit evaluation of non-dollar benefits must be introduced into the analysis. Let's say that after information on the character and impacts of non-dollar benefits is given to the decision-maker, he decides that these non-dollar benefits are half again as large (in dollars) as dollar benefits and that they have the same degree of uncertainty as dollar benefits. This would increase MBL and MBU at every pollutant reduction level by 50%, providing the marginal benefit schedules MBU' and MBL' respectively (see Figure 2). These marginal benefit schedules can be compared with marginal cost schedules to determine the range of control levels within which marginal costs equal marginal benefits with a confidence level of 90%, i.e., if the hypothesis is true, there is only a ten percent probability of making the mistake of rejecting it.

For example, consider MC1 in Figure 2. Marginal costs equal the lower 90% confidence level of marginal benefits at level A. At levels to the left of A, MBL' would be greater than MC1 implying that additional benefits can be gained by increasing the pollution control level. At levels to the right of A, MBL' is less than MC1 implying that net benefits are declining. Hence the best control level for maximizing net efficiency gains (i.e., total benefits minus total costs) at the lower 90% confidence level is to remove A tons of pollutant X per year. Similarly, removal level B would maximize net efficiency gains at the upper 90% confidence level. Assuming that emission source controls are implemented proportionately, this provides the control range AB within which the decision-maker can be 90% confident that net efficiency gains are maximized. Range CD is a comparable 90% confidence control range, assuming emission control is achieved by having every source incur the same marginal cost of control. As drawn in Figure 2, these hypothetical control ranges have relatively wide spreads meaning that the decision-maker can have little confidence that a specific control level within these ranges is, in fact, that level where net efficiency gains are maximized.[4]

Assume now that the decision-maker would like to set a level such that there is roughly a 90% chance that marginal benefits from pollution control will be covered by marginal costs. We can say that such a decision-maker has an aversion to risking excess pollution damage (relative to efficient damage levels) and that he is, perhaps, averse to legal challenges by environmental groups. Assume also that political realities favor proportionate control of pollution sources. Under these circumstances, the decision-maker would choose emission level B, promulgate the appropriate ambient air quality standard, and implement this standard by proportionate reduction in source emissions. Given a preference for marginally allocated reduction of pollutant X, the same decision-maker would instead, choose control level D and reap additional implicit efficiency gains of EB'D'F. But since he does not do this, income redistribution or burden considerations implied by using proportionate reduction must be at least equal to the foregone efficiency gain, EB'D'F.

Similarly, a decision-maker who has an unwillingness to risk excess pollution control costs (relative to efficient cost levels) would pick a control level near the other end of the control range. If the decision-maker wanted to set a level such that there were roughly a 90% chance that marginal costs would be covered by marginal benefits (say he was averse to legal challenges by industries having to control pollution), he would choose control level A, assuming proportionate reduction of emissions, or he would choose control level C, assuming marginally allocated reduction of emissions.

Choosing level A rather than C implies foregoing an implicit efficiency gain of EA'C'F in exchange for the income redistribution and burden "gains" implied by proportionate reduction. In other words, it is the relative price structure the decision-maker himself faces that matters.

An alternative way of presenting the information summarized in Figure 2 would be to: (1) consider, one-by-one, a number of control levels, each control level coupled with one of the two ways of reducing source emissions; and (2) characterize for each control level-source reduction pair the type of decision-maker who would choose a particular control scheme. For example, a cost-benefit analyst would describe a decision-maker, choosing control level B with proportionate reduction, in this way:

1. This decision-maker wants marginal benefits to equal or exceed marginal costs with a confidence level of 90%; he is likely to be adverse to legal challenges by environmental groups.

2. This decision-maker values <u>non-dollar</u> marginal benefits half again as much as dollar marginal benefits and believes that dollar and non-do-benefits have'the same degree of uncertainty.

3. This decision-maker is willing to forego an efficiency gain of EB'D'F in exchange for the income redistribution and burden "gains" implicit in proportionate reduction.

Information like this, for each control level reduction pair, could be presented to an actual decision-maker who would then have to ask himself: Which of these alternatives captures my (or my constituents') concerns and my (or my constituents') preferred tradeoffs?

So far, dynamic considerations have been glossed over in this presentation. Cost-benefit analysis should actually be carried out over some planning horizon. For a particular region and for particular pollutant sources, costs of pollution control are likely to decline over time as shifts are made from add-on control devices to process changes, and as advances in technology provide new, less costly control options. Likewise, for a particular region and for particular pollutants, pollution control benefits (i.e., avoided damages) might increase over time as population grows and as individual willingness-to-pa.v increases as incomes increase.

These considerations can be incorporated into cost-benefit analysis by modelling regional development and by estimating costs and dollar benefits over time and then discounting these to present values. This would provide <u>discounted</u> marginal cost and dollar benefit curves which could be analyzed exactly as the marginal curves of Figure 2 have been analyzed. Non-dollar benefits, as before, can only be described in physical terms although <u>implicit</u> values (relative to a chosen standard) can be assianed to them. Dynamic cost-benefit analysis is needed because different regional development policies will point to: different regional growth rates; different associated mixes of environmental standards and impacts; and different implementation times to meet such standards. These development tradeoffs should be made apparent to the decision maker.

This description of policy-making is not meant to be an absolute analytical framework. Events in the real world are highly uncertain; in many cases, little is known about the beneficial and harmful effects associated with pollution levels and about their "burden" impacts; it is not easy to model regional development over time. Nonetheless, cost-benefit analysis should at the very least, attempt to clearly spell out the implied and direct values which are involved in choosinq alternative levels of environmental quality.

HOW CAN GROSS BENEFIT ESTIMATES BE USED?

An attempt is made in this paper to review methodologies for estimating potential air pollution control benefits and to present a systematic tabulation of existing benefit estimates for the U. S. Most of these estimates generally relate to reductions in U. S. air pollution to levels required bv existing federal ambient air quality standards.

There is some danger that these estimates wi 11 be misinterpreted with respect to making precise policy decisions. To prevent this, questions about some of the numbers presented in this monograph will be posed and then answered using the preceding policy-making framework as point of reference. It is hoped that this excercise will clarify the meaning which can be attached to these benefit estimates.

Estimates for the U. S. of air pollution damages which can reasonably be measured in dollars range from a low of $6.1 billion to a high of $18.5 billion per year with a "best" estimate of $12.3 billion for 1970. Are current national primary standards too stringest if the costs, for the U. S. of meeting national primary standards, are $40 billion per year? What if, instead, the costs are only $5 billion per year?

On the basis of the information provided, it is not possible to answer these questions. Here are several reasons:

1. Only single alternative cost estimates and a single dollar benefit estimate with high and low spreads are provided in this example. Economic analysis of environmental tradeoffs requires cost and benefit functions. In other words, it is necessary to find the range of control levels at which marginal costs equal marginal benefits. Information on total costs and dollar benefits for a single control level are not adquate to judge whether or not costs and benefits are reasonablv equal at the margin.

2. No information is provided here on the characteristics and the distribution of those benefits which cannot reasonably be measured in dollars. These non-dollar benefits--such as psychic benefits--do exist and they are likely to be quite large. Even if control costs are substantially greater than dollar benefits, non-dollar benefits could be sufficiently large at the margin to justify quite stringent policies.

3. No information is provided on "burden" impacts. Who pays? Who benefits? Who suffers residual damage, i.e. that damage remaining even after desired levels are achieved? This information is needed to measure the reasonableness of the "burden" tradeoffs implicit in national policies.

4. No information is provided on regional costs and benefits and regional burdens. Without this it is impossible to determine whether or not the costs exceed the benefits in any region at the nationally determined levels.

5. No information is provided on pollutant-specific costs and benefits and burdens. Without this, it is impossible to determine whether or not pollutant tradeoffs, relative to nationally determined levels for specific pollutants, are reasonable.

6. No information is provided on what is happening to regional costs and benefits and burdens and to regional development over time. Without this information, it is impossible to know whether or not nationally determined levels are dynamically efficient.

If air pollution damages in the U.S. are estimated to be $12.3 billion for 1970, what is an appropriate use of this estimate? This estimate tells us that in an aggregate sense, air pollution is a relatively serious problem and that we should probably attempt to reduce air pollution emissions. The level to which emissions should be reduced, however, can only be determined by undertakinq a series of quite complicated regional cost-benefit or tradeoff analyses, each in concept like the one described previously.

There are several recent applications of gross estimates of air pollution damaqe to cost-benefit analyses that are worthy of mention. One is the application made in the Economics of Clean Air[5] where it is shown that the present government program of promulgating air quality standards is justified on the. basis of gross damage estimates generated by Barrett and Waddell (1973). Another recent application is in the report prepared for the Office of Science and Technology, Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT)[6], in which it is concluded that present estimates of air pollution damage (again, taken from the Barrett-Waddell report) raise serious questions about the justification of the stringency of the legislated mobile source emission standards. It is quite evident that such gross damage estimates can only be used meaningfully when the user has a thorough understanding of their limitations.

In summary, gross benefit estimates will be useful to environmental managers, but only in a limited way. They will provide some measure of the seriousness of the air pollution problem. Yet such estimates will not provide the environmental manager with the kind of information that is needed to establish environmental quality standards. If the manaqer is to consider realistically the tradeoffs in setting such standards, information in the form of functions that relate costs to varying levels of emission control and damages to varying levels of air quality are needed. The damages-air pollution relationships--the damage functions--can be constructed using one of several methods. These methods will be discussed in the next section.

SECTION III

METHODS OF ASSESSING AIR POLLUTION DAMAGE

OVERVIEW

As discussed earlier, it is difficult to relate economic damages to varying levels of air quality. Such functions that relate economic damages to varying levels of air quality--damage functions--can be viewed as society's demand schedule for pollution abatement.[7] The demand curve for cleaner air is a schedule of what people would be willing to pay for various levels of air quality if the world, except for air pollution, were efficiently organized.

The various methods that economists use to estimate damages from air pollution have been discussed to some degree or another by Kneese,[8] Ridker,[9] Crocker,[10] Lave,[11] and Anderson and Crocker.[12] There are six general methods that have been used with different degrees of success. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys. of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the delphi method. The six methods are not necessarily mutually exclusive, but each is distinct enough to justify individual treatment in this section.

The strengths and limitations of each method, and how they have been employed are also discussed in this section. Applications of the different approaches will be discussed in detail in later sections.

INDIVIDUAL METHODS

Technical Coefficients of Production and Consumption

Copious literature exists concerning the physical and biological effects of air pollution upon artifacts and organisms. For example, there is well documented evidence that: particulates and oxides of sulfur exacerbate respiratory diseases in humans (Lave and Seskin, 1970); oxidants severely inhibit the growth rate and yield of citrus and grapes (Benedict et al., 1971); and oxides of sulfur cause excessive corrosion of metals (Fink, et al., 1971). In general, the method is developed by: (1) derivation from experimental data by the observations on objects in conditions simulating their natural environment; (2) estimation of the physical or biological damage function which relates damage to pollution levels; (3) translation of the physical damage function into economic terms; and (4) extrapolation of the function to the population, using appropriate coefficients, if an aggregate damage estimate is desired.

Because of the lack of adequate dose-response functions, a variation of the basic method outlined above is followed. In what might be termed a "damage factor approach," the investigator will estimate what proportion of a damage category can be identified as being related to or caused by air pollution. Then by applying this proportionality factor to the damage category, estimates of air pollution damage can be determined. Good examples of this damage factor approach are given in studies by Lave and Seskin (1970) and Benedict, et al. (1971). These as well as other applications of this method will be discussed in more detail in Sections V, VI, and VII.

In many cases, the magnitudes of these physical and biological damages can be predicted with some degree of accuracy because the forms of damaqe under restricted conditions are known. Attempts to translate these physical and biological damages into meaningful economic relationships have been less successful in identifying economic damaqes over a range of pollution exposures. Success in this method has been obtained onlv within narrowly circumscribed limits. Why? Because controlled laboratory conditions usually have little semblance to real world conditions. To minimize the confounding effects of other causal factors in the real world, the normal scientific method holds everything constant except one factor (in this case, a single pollutant or mix of pollutants). For purposes of generating damage estimates, the extrapolation of laboratory results to the true world is risky. Such a process ignores possible nonconstant marginal products, factor proportions, nonlinearities, jointness, etc.

Other problems are those of aggregation and substitution. Crocker[13] has argued that to obtain anything vaguely resembling a market estimate of collective damages, some means of making individual receptors (i.e. those who suffer damage) commensurate must be found; and then, only rarely will the aggregation process involve a straightforward arithmetic summation over all individual properties. Anderson and Crocker go on to say, "However, the collection of receptors cannot simply be treated as some arithmetic sum of individual receptors, for the prices of the substitution possibilities the single receptor views as fixed are not necessarily fixed for the collection of receptors."[14] That is, the substitution of one input by an individual will not normally affect relative prices, but if the same substitution is carried out by all receptors, then relative input prices will often be changed. The problems in employing the technical coefficients approach are those of: (1) extrapolation from controlled research environments to real world conditions; (2) aggregation of damages; and (3) enumeration of the technically feasible and then the technically efficient possibilities because of substitution,

Even given these limitations, this is the method that has been most widely used. And given the adaptability of the method of focusing on a single receptor and effect, the studies are quite amenable to the development of <u>gross</u> damage estimates.

Market Studies

In this approach, air pollution damages are measured through the explicit use of market. valuations. The consideration, here, is the impact of air pollution dosages on human behavior as reflected in markets. This approach completely circumvents the need to know the physical or biological damage function--the basic dose-response relationship. The investigator applies statistical tools and econometric models to market data to isolate the incremental adverse effect of air pollution on a particular activity or behavior as expressed in the market place.

One particular type of market study of interest is the indirect effect of air pollution on expenditures for a particular product or activity. A good example of such a study is one by Vars and Sorenson (1972). In their study, they attempted to explain the relationship between air quality and consumer behavior, or more specifically, the consumption of recreation-related activities.

Another type of market study is the use of property values to estimate air pollution damages. One of the significant features of air pollution is its locational nature, Fortunately, then, there do exist markets in which the services and/or disservices of air pollution can be measured. As Ridker said, "If the land market were to work perfectly, the price of a plot of land would equal the sum of the present discounted stream of benefits and costs derivable from it...Since air pollution is specific to locations and the supply of locations is fixed, there is less likelihood that the negative effects of pollution can be significantly shifted onto other markets. We should, therefore, expect to find the majority of effects reflected in this market, and can measure them by observing associated changes in property values."[15]

Thus, given that people are willing to pay to avoid the effects of air pollution, property values and air pollution concentrations must vary inversely. Measures of this relationship, obtained through common multivariate estimation techniques, should yield rough estimates of the air pollution damages.[16] Good examples of this approach are given in documentation by Ridker and Henning (1967), Anderson and Crocker (1970), Peckham (1970), Crocker (1971). and Spore (1972).

The investigator will face a very significant problem in using the market study approach: he must account for all the factors that explain consumer preferences and behavior. Such an explanation is, of course, a monumental task, both theoretically and empirically.[17] And then, when robust statistical relationships have been compiled, there is the difficulty of interpreting the causality and relative importance of those pollutant measures accounted for in the study. The investigator must be sensitive to the possibilities of spurious relationships.

With respect to the causality problem, if there is a high degree of intercorrelation between two pollution measures, too much significance should not be attached to the magnitude of the coefficients of the individual pollution variables. Pollution tends to be a composite phenomenon. That is, the presence of one pollutant is frequently a reliable-hint that others are also present. Thus, it is possible that the pollutants measured by these variables are not the causative agents, but are simply surrogates for others that are producing the undesirable effects.

A common criticism of the property value method is that for the method to have validity, buyers must know that pollution differs at various sites. Actually, buyers need only know that they prefer some properties to others, and other things equal, are willing to pay more for the preferred properties. If the non-preferred properties contain attributes or effects of pollution, this is sufficient for a differential property value to result. The notion of cause and effect thus rests wholly in the mind of the investigator, and not necessarily in the mind of the property buyer.[18]

Obviously, the important question arises: "What effects of air pollution are discounted and what effects are capitalized in the property market?" In other words, to what extent does the property value estimator reflect the true or complete damage cost of air pollution?

It is possible that this estimator may be biased if a good deal of air pollution injury is so insidious as to escape consumer notice. Yet public opinion surveys seem to indicate that such has not happened.[19] Ayres believes that the real estate market primarily reflects the tangible, experiential aspects of pollution: more rapid deterioration and extra cleaning and maintenance costs; the milder medical symptoms, such as shortness of breath and smarting eyes; plus, smells and dirt.[20]

Most investigators agree that costs associated with organoleptic effects (including psychic) as well as soiling-caused cleaning and maintenance expenditures are capitalized in this estimator.[21] This assumption appears consistent with the conclusion recorded by the Surgeon General's Ad Hoc Task Group on, Air Pollution Research Goals which states: "The aspects-of air pollution which are most apparent and of greatest personal concern to the individual probably are irritatio to the eyes, nose, and throat, malodors, and the reduction of visibility. The pollutants responsible for these effects are undesirable whether or not they cause long-range health effects or economic losses, because they constitute an annoyance to people. The nuisance aspects of these effects together with those related to soiling give rise to the greatest number of complaints received by air pollution authorities. There is no doubt that a person's well-being is eventually affected by exposure to these sensory annoyances and that this may result in economic loss."[22]

Another difficulty in using this approach was voiced by Freeman: no general equilibrium model has yet been developed that is capable of predicting land or site values following some given change in air quality.[23] He argues further that ". ..empirical studies of land values and air pollution should await the formulation of general models from which empirically testable hypotheses can be deduced. Until such models are formulated and tested, empirical land-value studies will make little or no contribution to our knowledge of the benefits of air pollution abatement."[24] Anderson and Crocker argue that a general equilibrium model does exist in the form of an assignment model.[25] Furthermore, the model has been subjected to a test' of sorts.[26]

In fact, there seems to be embodied in some work by Strotz[27] an equilibrium model acceptable to Freeman and at the same time, quite consistent with Anderson and Crocker's hypotheses. The model appears to be operational though it has not yet been fully tested. It can be termed a general equilibrium model in a pure exchange setting.[28]

Even so, Anderson and Crocker conclude that a partial equilibrium model, designed to explain the differentials in site values that exist at a given point in time, can be used to predict the change in the value of a representative site that would accompany a change in air quality, other things being equal. The implied damage cost estimate, properly interpreted as the marginal capitalized loss due to air pollution, does provide valuable information concerning the nature of air pollution damages being suffered.

Then comes the inevitable question: "What portion, then, of pollution damages are measured by the property value estimator?" Theory would state that if all consumers do not regard the two sites as perfect substitutes for each other when each site has equal air pollution dosages, then some air pollution damages will be registered in other durable assets and losses in consumers' surplus. Property value differentials, then, can be employed to obtain a lower bound on air pollution damages, and, if the sites in question have rather homogenous characteristics, their differential values represent all or nearly all damages.[29] Spore states that at a minimum, since people exposed to pollution dosages will relocate only if the pollution costs they can avoid plus the costs of moving are greater than the costs of using some alternative less-polluted site, then the costs of this adjustment (moving) will be reflected in site-value differentials.[30]

Another type of market study has been identified as the compensating income, approach. That is, people who live in relatively dirty environments are, on the average, compensated by relatively higher incomes. Only little empirical work has been undertaken in this area.[31]

Opinion Surveys of Air Pollution Sufferers

In an era when Gallup and Harris polls are as commonplace as interest in the constellations, it seems quite appropriate (and popular) for those who have responsibility in making decisions about environmental management, to be concerned about public opinion. And indeed, this approach is closest to the classical economic approach in that it focuses on estimating utility and demand functions. For example, a recent opinion survey by Opatow Associates attempted to measure the public's awareness and reaction to pollution.[32] Of particular interest was the extent to which concern by the public about environmental pollution affected consumption patterns. And, the effects of pollution on consumption are what economists want to measure.

In a November 1970 popularity survey, a nationwide poll conducted by Harris showed that "pollution" ranked as the most serious problem facing many communities.[33] In a December 1971 Gallup poll, 52% of the people questioned expressed a "deep concern" about environmental pollution.[34] Such techniques have also delved into the economic aspects of the problem. In the same Gallup poll, 8% of the respondents said that they would be willing to pay $100 or more per year in added taxes "to improve our natural surroundings," and 46% said they would be willing to pay only an extra $10 or less per year.[35]

Investigators employing this method, have attempted to ascertain what people do and do not perceive as air pollution effects, distinct from whether or not they know the cause of the effects.[36] This distinction is important, for as with the property value method--contrary to the confusion on the subject--in order to determine air pollution effects, it doesn't matter whether people recognize the cause of these effects.[37] The notion of cause and effect need rest only in the mind of the investigator.

If it can be assumed that people know explicitly the effects of air pollution, then the objective is to elicit complete information from them in a way that would dissuade untruthful responses. It is well known that sample polling questions like "what would you be willing to pay to avoid (or gain) so and so," often yield misleading answers. Since every person questioned actually pays nothing to have his opinion recorded, he can respond by making extreme statements in the hope of indirectly influencing policy.

Also important in interviewing is the "free rider" aspect. Air pollution control can involve a "free rider" problem because air pollution is indivisible and pervasive in nature and moves about freely. If the respondent feels that the sum to be collected is large, he will name an arbitrarily low figure. This is the conventional problem of public goods: the interviewee reasons that even if he doesn't pay, he will be able to enjoy something others are paying for. He doesn't want to pay for abating pollution when it will benefit everyone.

Finally, there is the possibility that a respondent might not understand fully the consequences of air pollution on his health, for example. Again, in the case of health, one might be unable or unwilling to think about such consequences in purely economic terms.

Inspite of many of these problems, the opinion survey approach does have its usefulness. Information on a sufferer's preception of air pollution and his attitudes toward it can be obtained by the use of questionnaire interview studies. Interviews can also provide the investigator with the sufferer's understanding of the type, nature, and extent of air pollution effects. To the extent that this knowledge is used as a basis to improve sufferer information so that he will make more complete adjustments, the air pollution damage function will be changed. Findings from studies employing the opinion survey approach are quite sketchy. These kinds of studies will be reviewed primarily in Sections IV and VIII.

Opinion surveys have shown particular usefulness in understanding: (1) how attitudes about air pollution are formed and then affected by changes in air quality; and (2) what people do and do not perceive as air pollution effects. This method can also provide some insight into what people might be willing to pay for improvement in the air environment, or perhaps, what their demand might be for the reduced risk of experiencing certain adverse effects,

Obviously, concern over the environment and individuals' ability to pay are important factors in determining willingness to pay for the abatement of air pollution. It can be shown with conventional economic theory that given one's knowledge, he purchases that much clean air to where the benefit of the last increment purchased equals the cost of abating by that last increment. By acquiring more knowledge (at a cost, of course) of the effects of air pollution, an individual's willingness to pay for different levels of air quality (i.e. pollution control) would probably change. Given the difficulty of measuring people's knowledge, it is likely that other measures will have to be used in conjunction with the interview method to determine the demand schedule for a cleaner environment.

The willingness-to-pay, if correctly determined, indicates the demand for a cleaner environment. However, it does not include the damages (say to -health) that accrue to persons who cannot, or, because of low income, are unwilling to pay anything to avoid the damages. Here, the damage to an affluent person would be valued more than the same damage to a poor person.

It seems that one particular area where this method might prove very useful is in understanding the aesthetic or psychological effects of air pollution. Ridker's (1967) attempt at reaching this understanding indicates some promise. And as the general public becomes more knowledgeable about the effects of air pollution (and this can be determined through the use of the interview method), then this approach will become even more useful in understanding what people are willing to pay for varying levels of air quality.[38]

Litigation Surveys

By 1969, after many attempts at estimating pollution costs, it was sensed: that personal opinion polls often did not yield truthful responses; that surveys of the technical coefficients of household production functions failed to pick up the myraid adjustments to pollution loadings; and, that property value studies were only as good as the data used in,them--and the data were often weak. It was hoped that some new technique could be developed to circumvent the difficulties of the traditional estimators. Perhaps legal cases would suggest some way of deriving information on air pollution damages from the decisions of the judicial system in adjudicating conflicts of interest over air resources.

A litigation survey project of Philadelphia cases, undertaken by Havighurst (1969) and his staff, originally had two major objectives: First, they were to locate and report in sufficient detail, all litigation--at the original or appellate levels--that might bear on the problems of finding out how much air pollution costs. Further, they were to determine the extent to which the people of Philadelphia have turned to the courts for redress. Second, using the information gathered from the study, they were to evaluate judicial data as estimators of damage functions.

The investigators spent many hours talking to lawyers, court clerks, state and local control officials and anyone who might have knowledge of past or pending litigation relevant to the search. In all, three useful cases in Philadelphia were found. Havighurst concluded that citizens of urban areas are much less inclined to attempt to control pollution through private legal action than are citizens of less polluted areas;[39] city dwellers become conditioned to air pollution. And, in a dense industrial city, there is some difficulty in knowing just what sources are primarily responsible for the pollution. Due to the paucity of interesting cases in the Philadelphia area, the project was broadened to include the Berks County-Bethlehem region. Except for a few cases which turned up, this effort, too, proved unavailing.

It was obvious that no damage functions, or even much useful data, would emerge from the records of the few cases that had been located, and therefore the most important thing to be done was to evaluate carefully the feasibility of using litigation information as a means for measuring pollution damage.

To proceed on such an appraisal required a careful comparison of the type of damage information desired by economic analysts and the type yielded by the courts; Noting that most courts, in practice, make nuisance awards on the basis of the estimated decline in the market value of the injured property and on the basis of the court's allowance for special "discomfort and annoyance," Havighurst concluded that the economic usefulness of such awards depended on the similarity between the preferences of the market and the preferences of those actually injured. In deriving estimates of economic damage, 'the more these preferences coincided, the stronger the case of disregarding the court's special annoyance allowance.[40]

A final product of the project was a recommendation that litigation surveys of this type be continued. Despite the lack of success in the Philadelphia area, it was felt that a national survey, perhaps of cases involving odors, would turn up enough damage awards that some tentative functions might be drawn. Haviqhurst suggested, however, that legal records as they now stand are frequently unsatisfactory for this'purpose due to a failure to itemize pollution injuries and to specify the ambient air quality involved in the nuisance conditions.

Political Expressions of Social Choice

In utilizing this approach, one tries to gauge political expressions, representations, and exhortations in the hope that their intensity somehow corresponds to intensity of preference for one outcome over another. Yet, assessments of the outcomes of political expressions are not likely to be accurate indicators of what receptor preferences for one state of air quality relative to another would be in any real market situation. The intensities of social choice registered by political means represent only the relative valuations that occur under the constraints imposed by the political process. As such, they reflect the ability of the voter to alter the relative prices he faces.[41]

While no formal efforts have been made to specify the magnitude of the damages which usually emerge in these processes, the numerous environmental newsletters provide some appreciation for the intensities of social choices by focusing on reports where voters or taxpayers have supported (or failed to support) the passage of bond referendums, or where legislators have raised taxes to finance the construction of some pollution control activity or facility.[42]

Delphi Method

This approach, as stated by Pill, is ". ..a method of combining the knowledge and abilities of a diverse group of experts to the task of quantifying variables which are either intangible or shrouded in uncertainty."[43] Essentially the method is one of subjective decision-making. It is an efficient way to produce best judgments where the knowledge and opinion of experts are extracted. Desiring a particular output, those who are considered experts in the relevant area are asked to give their best solution to any given problem. This method is one that has been used by the U. S. Department of Agriculture in forecasting crop. production levels. The estimate, as generated by the U. S. Department of Agriculture, of $325 million in crop losses-due to air pollution, appears to have been developed in such a manner.[44] Another estimate apparently generated in such a manner is the $40 to $80 million annual cost of the adverse effects of air pollution on air travel.[45]

The Delphi method appears to be an approach that can provide quick answers in a short time frame. Yet, due to its subjective nature, many of'the air pollution damaqes generated in this manner, have been, and probably should be largely ignored. Yet as Dalkey said, "We can either wait indefinitely until we have an adequate theory enabling us to deal with socio-metric and political problems as confidently as we do with problems in physics or chemistry, or we can make the most of an admittedly unsatisfactory situation and try to obtain the relevant intuitive insights of experts and then use their judgments as systematically as possible. The use of the Delphi approach represents an effort to proceed along the second of these alternatives."[46]

WHAT METHOD IS BEST?

Of the six methods surveyed, the technical coefficients of production and consumption, opinion surveys of air pollution sufferers, and a particular market study application, the property value method, have yielded the most promising insiqhts into the true nature of air pollution damages. Yet even the application of these methods has been fraught with many problems. Air pollution is but one environmental stress, and there are no satisfactory methods of allocating the observed damages among a number of synergistically interacting multiple stresses, nor can the damages themselves be easily measured and reduced to economic terms.

Because of its seneral ease of measurement and inclusiveness, the property value, or site value differential technique, is one of the more promising approaches to the estimation of the economic losses due to air pollution. The advantage of this method is that the investigator does not have to discover and evaluate the pollution sufferers' adjustment possibilities, nor does he have to worry about how to make individual properties commensurate so that he can aggregate them, The housing market does it for him throuqh directly observable market prices,[47] It is simply the investigator's job to correctly specify the separate influence of each characteristic, including air pollution, so that each's influence on air pollution can be discerned by well-known statistical techniques.

Two significant limitations of the property value technique which result in the underestimation of true damage costs, are: (1) the extent to which certain minimum levels of pollution are pervasive over all properties in a market, nothing could be gained by the receptor in relocating; and, (2) since there are many long-run, chronic effects that are not easily measured, it is doubtful that this technique would discern these effects. As stated earlier, concern over the limited ability of this approach to reflect even major effects, has been expressed by Ayres and Lave.

Applications of the technical coefficients approach also, can provide information on the damages of air pollution. Given that all damages will not be registered in the property value approach, the technical coefficients approach can provide insight into the fundamental processes of receptor response where air pollution has its impact. The technical coefficients and property value approaches, then, can provide complementary information. The property value approach has the advantage of ease, whereas the technical coefficients approach has the advantage of providing insight into fundamental processes.

A deeper understanding of the fundamantal adjustment processes of the receptor can also be gained by employing the interview approach. This approach can be used to determine what effects receptors perceive or fail to perceive. The information obtained can also be quite valuable for analyzing the subtle effects of air pollution. Thus, the interview approach can provide the investigator with information about receptors who suffer from air pollution effects.[48] This knowledge can be used as a basis to improve the information that sufferers have so that they will make more complete adjustments. This information, in effect, will result in some shift in the air pollution damage function.

The litigation, political expressions of social choice, and delphi approaches have been somewhat less successful in measuring the damages of air pollution than technical coefficients studies, market studies, and opinion surveys. An evaluation of the litigation approach shows that there is a theoretical problem of distinguishing between economic costs and legal costs. Also, there is the general problem that court decisions usually lack adequate dose-response information. The severe constraints and complexities of the political process afford little opportunity in determining the value of marginal changes in voters' preferences.

Given the dearth of air pollution dose-response information, it is possible that the delphi method which relies on subjective opinion rather than objective data, will be used in a more significant way. It seems obvious that where substantial information is missing, the pooled judgments of experts could provide useful information to the decision-maker on the genera1 magnitude of damages over a range of pollution levels.